EMC Global Model Upgrades Since CFSv2 Implementation

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representing

Global Climate and Weather Modeling Branch

and Marine Modeling and Analysis Branch

EMC/NCEP

Outline

- **Global models in current operations**
  - **coupled (CFS)**
  - **uncoupled (GFS)**
- **Atmosphereic model changes since the CFSv2 implementation**
- **Other available options**
- **Ocean model development**
- **NOAA Environmental Modeling System (NEMS)**
- **Hybrid EnKF/3DVAR analysis system**
- **Aerosol and Chemistry modeling**

Global Models in Current Operations
(*Coupled*)

- ***Climate*** (**C**limate **F**orecast **S**ystem aka CFS)

  - **CFSv1** – T62L28 GSM coupled to GFDL MOM3 OM and OSU land model - **implemented in 2004**

    Initial conditions from R2 atmospheric assimilation and MOM3 based GODAS forced with R2

    (expected to be discontinued on 31 October 2012)

  - **CFSv2** – T126L64 GSM coupled to GFDL MOM4 OM and a sea-ice Model and Noah land model

    Initial conditions from quasi-coupled T574L64 atmospheric assimilation and MOM4 based oceanic assimilation (**CDASv2**). **Implemented in March 2011**

Atmospheric Model changes in CDASv2 from CFSR

- **Eulerian T574L64 (vs T382) version for first guess forecast**
- **Updated Gravity-Wave Drag Parameterization due to increased horizontal resolution**
- **Removal of negative water vapor through positive-definite vertical transport of tracers and other minor upgrades**
- **Updated Radiation and Cloud properties (details in backup slide)**
- **Both CDASv2 and CFSR use enthalpy as a prognostic variable**

Atmospheric Model in CFSv2
(same as that used in retrospective forecasts)

- **T126 horizontal resolution with hybrid sigma-pressure in the vertical**
- **Stratus related changes turned off (i.e. issues with marine stratus)**
- **McICA formulation of RRTM radiation**
- **Mixing ratio for in-cloud condensate is taken as grid-mean value/ cloud-cover in computing cloud optical thickness**
- **Land Surface Model parameters related to precipitation runoff retuned**
- **Vertical advection of tracers not positive-definite**

Current Radiation package in CFSv2
Collaboration with AER Inc.

- **RRTMG with McICA**
- **Hourly LW and SW**
- **Maximum/random cloud overlap with homogeneous water/ice clouds**
- **Observed /estimated CO2 with 15 degree horizontal resolution**
- **Trace gases – prescribed global mean climatology**
- **Solar constant 1366 w/m2 (11 year solar cycle – Van den Dool)**
- **Tropospheric aerosols based on 5 degree monthly climatology**
- **Stratospheric aerosol from historical observations in four latitudinal bands.**
- **Land albedo - surface vegetation type based monthly climatology**
- **Ocean albedo - prescribed + empirical Cosz adjustment**
- **Emissivity prescribed based on obs/climatology.**

Global Models in Current Operations
(*Uncoupled*)

- *Weather* (**G**lobal **F**orecast **S**ystem aka **GFS**)

- Global Spectral Model (GSM) with Noah Land and a simple sea-ice model and Global Statistical Interpolation (GSI)
- Global Data Assimilation
  - T574L64 GSM first guess – GSI DA on linear grid of T574
- Global Deterministic Forecast
  - T574L64: 0-192 hrs
  - T190L64: 192-384 hrs
  - 4 times daily
- Global Probabilistic Forecast – GEFS with Stochastic perturbations
  - T254L42: 0-192 hrs, 20 members each cycle
  - T190L42: 192-384 hrs
  - 4 times daily

Atmospheric Model Physics (GFS)

Planetary Boundary Layer and vertical diffusion (PBL)

- **Nonlocal PBL scheme originally proposed by Troen and Mahrt (1986) and implemented by Hong and Pan (1996)**
- **Recent update (2010)– stratocumulus top driven vertical diffusion scheme to enhance diffusion in cloudy regions when CTEI exists**
- **For the nighttime stable PBL, local diffusivity scheme**
- **Background vertical diffusion:**
  Exponentially decreasing with height for heat and moisture
  A constant value of 3 m2/s for momentum up to sigma=0.2 and exponentially decreasing above
  Decreased by 70% in inversion layer below 2.5km over ocean to improve near coastal marine stratus

Atmospheric Model Physics (GFS)

Shallow convection parameterization

- **A new mass flux based shallow convection scheme was implemented in July 2010 (Han and Pan, 2011)**
  - **Detrain cloud water from every updraft layer**
  - **Convection initiated from the level of maximum moist static energy within the PBL**
  - **Cloud top is limited to 700 hPa**
  - **Entrainment rate is inversely proportional to height and detrainment rate is set to a constant equal to the entrainment rate at the cloud base**
  - **Mass flux at the cloud base is specified as a function of convective boundary layer velocity scale**

- **Original shallow convection scheme (Tidtke, 83) with an option to limit the cloud top to below low level inversion in the absence of CTEI is still an option and produces reasonable marine stratus (used in CFSR)**

Atmospheric Model Physics (GFS)

Deep convection parameterization

- **Simplified Arakawa Schubert (SAS) scheme is used operationally in GFS (Pan and Wu, 1994, based on Arakawa-Schubert (1974) as simplified by Grell (1993))**
- **A single deepest possible cloud-type per every time step**
- **Cloud water is detrained from every cloud layer**
- **Specified finite entrainment and detrainment rates for heat, moisture and momentum**
- **This implementation resulted in reduced occurrences of excessive grid-scale precipitation**

Radiation package under development for GFS

- **Updated and optimized RRTMG + Neural Net Emulator option**
- **Higher frequency of radiation calls (possibly every time step with NN)**
- **Uncorrelated cloud overlap & inhomogeneous water/ice clouds with rain/snow**
- **Updated CO2 with vertically varying profile**
- **Observed estimate of Trace gases – prescribed global mean climatology**
- **Mean Solar constant of 1361 w/m2 (with 11 year solar cycle – Van den Dool)**
- **GOCART interactive aerosol model, updated with vertical profile**
- **Land albedo using MODIS retrieval based monthly data**
- **Ocean albedo based on salinity, surface wind and Cosz**
- **Spectrally varying emissivity**

NN emulations of Model Physics

- Any parameterization of model physics is a continuous or almost continuous mapping, i.e., relationship between two vectors:

$$Y = F(X); \quad X \in \Re^n, Y \in \Re^m$$

- NN is a family of functions:

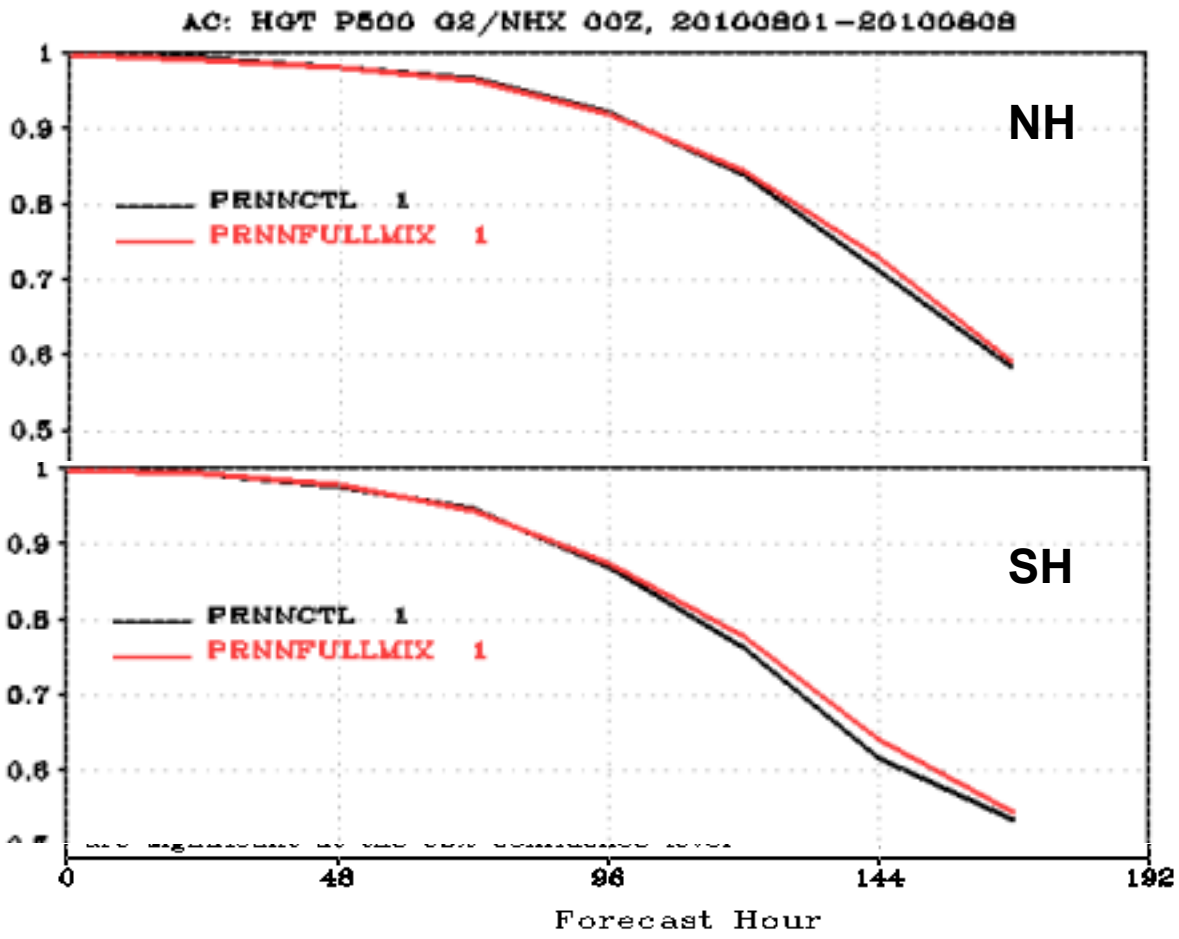
$$Y = F_{NN}(X) :=> y_q = a_{q0} + \sum_{j=1}^{k} a_{qj} \cdot \tanh(b_j + \sum_{i=1}^{n} b_{ji} \cdot x_i); \quad q = 1,...,m$$

which can emulate any continuous or almost continuous mapping; thus, any parameterization of model physics can be emulated using NN

- **NN is very fast**

500 hPa Anomaly Correlation Die-off Curve

Test dates 1-8 August 2010



Two GFS (T574L64) runs are shown: black line – control run with the original LWR and SWR and red line – run with NN SWR and LWR .

Speedup:

LW ~ x 20

SW ~ x 100

Other Upgrades and/or options in GFS

- A restructured GFS is being run in hybrid EnKF pre-implementation parallel (expected to be implemented in 22 May, 2012)
- A **two time-level semi-Lagrangian semi-implicit dynamics** following ECMWF's approach (original GFS code by Late Dr. Sela)
- This SLSI option is being tested at **T1148** with linear grid
- **Generalized hybrid coordinate** option which can be used with or without **enthalpy** as a prognostic variable (used by SWPC in WAM)
- **NDSL semi-Lagrangian** option by Dr. Henry Juang

Additional Upgrades and/or options in GFS

- Original Tiedtke's shallow convection with modifications which produce realistic marine stratus

- **Ferrier microphysics** (from NAM)

- **Relaxed Arakawa-Schubert (RAS)** cumulus parameterization with recent modifications that reduces precipitation bulls eye.

- **Near surface sea-temperature model** (NSTM)

  (See Dr. **Xu Li**'s presentation in this workshop)

  Multi-model ensemble with a single executable is possible.

Long-Term Global Atmospheric Modeling Plans

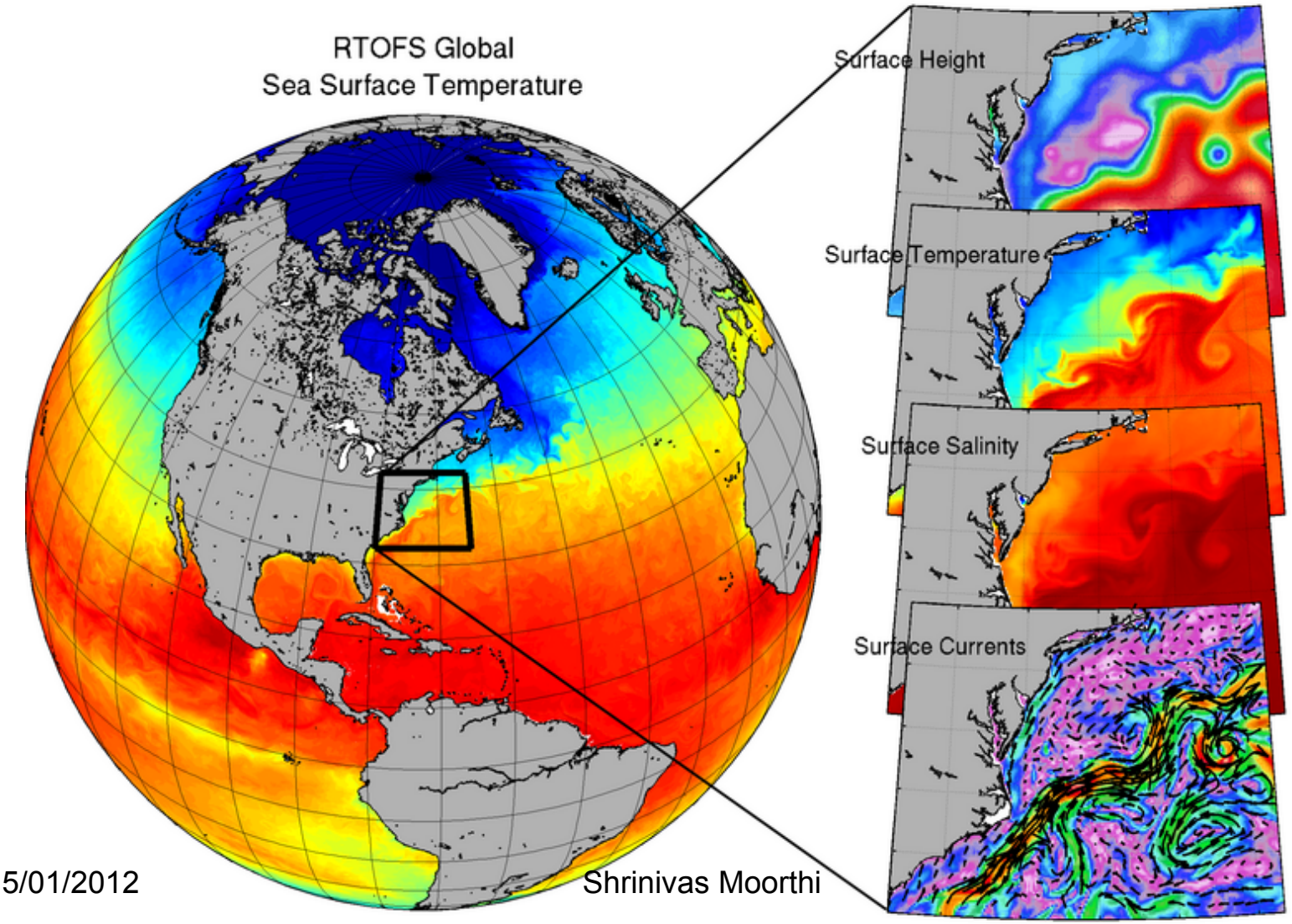
- There are other atmospheric modeling systems, both internal & external to NOAA, that can be applied to the Global Climate and Weather modeling problem.
  - ESRL NIM
  - NCAR MPAS (Fanglin Yang is at NCAR right now)
  - GFDL Cubed sphere
  - NCEP NMMB
  - ESRL FIM

- These models could be considered for the deterministic model or as an ensemble member

Global Real Time Ocean Forecast System (RTOFS-Global)

- **RTOFS-Global is the first operational global eddy-resolving ocean forecast system at NCEP**
- **Partnership with US Navy**
- **This global system is based on a 1/12 degree HYCOM (HYbrid Coordinate Ocean Model) with a Pan-Am Global Grid (4500 x 3928)**
- **The system has 32 vertical hybrid layers (isopycnal in the deep, isolevel in the mixed layer and sigma in shallow waters)**
- **The initialization is based on a MVOI scheme (NCODA) developed by the US Navy which assimilates daily observations (T,S, U,V and sea surface height) in a sequential incremental update cycle to produce analysis**
- **The daily global ocean forecasts at NCEP are forced with the GFS surface fluxes of radiation, precipitation and momentum**
- **Once daily six day forecasts**

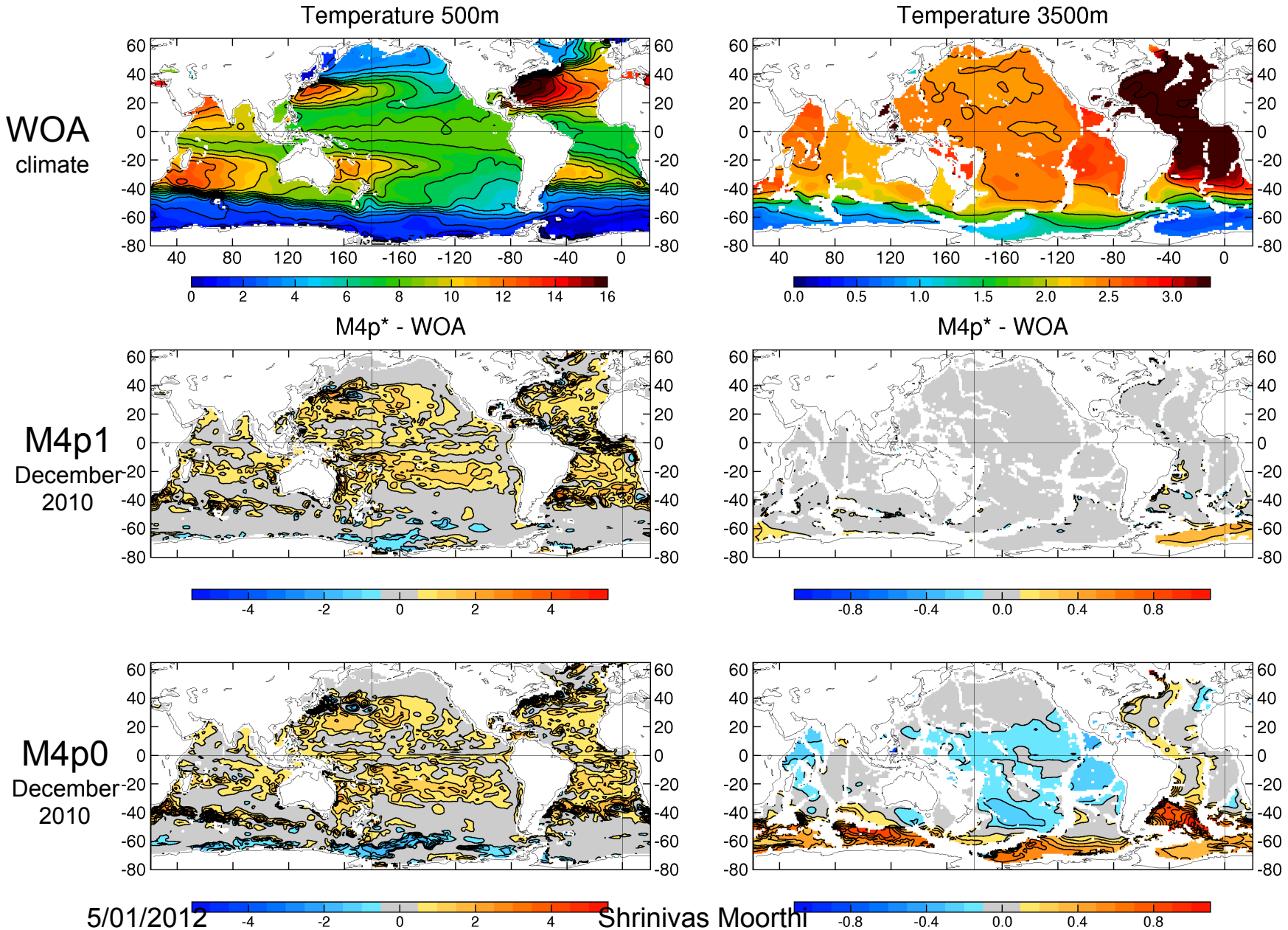
RTOFS Global: Daily 6 days forecast



RTOFS Global future enhancements/applications

- NCEP initialization based on 3dVar/Hybrid schemes (NCODA, LETKF) - Target for next CCS upgrade (2014)
- Nested Basin Models
- Coupled Hurricane forecast systems for Pacific, Indian oceans - Initialization, boundary conditions, nesting
- **Potential ocean component for future CFS versions using NEMS** (Based on ESMF, NUOPC prototype layer)

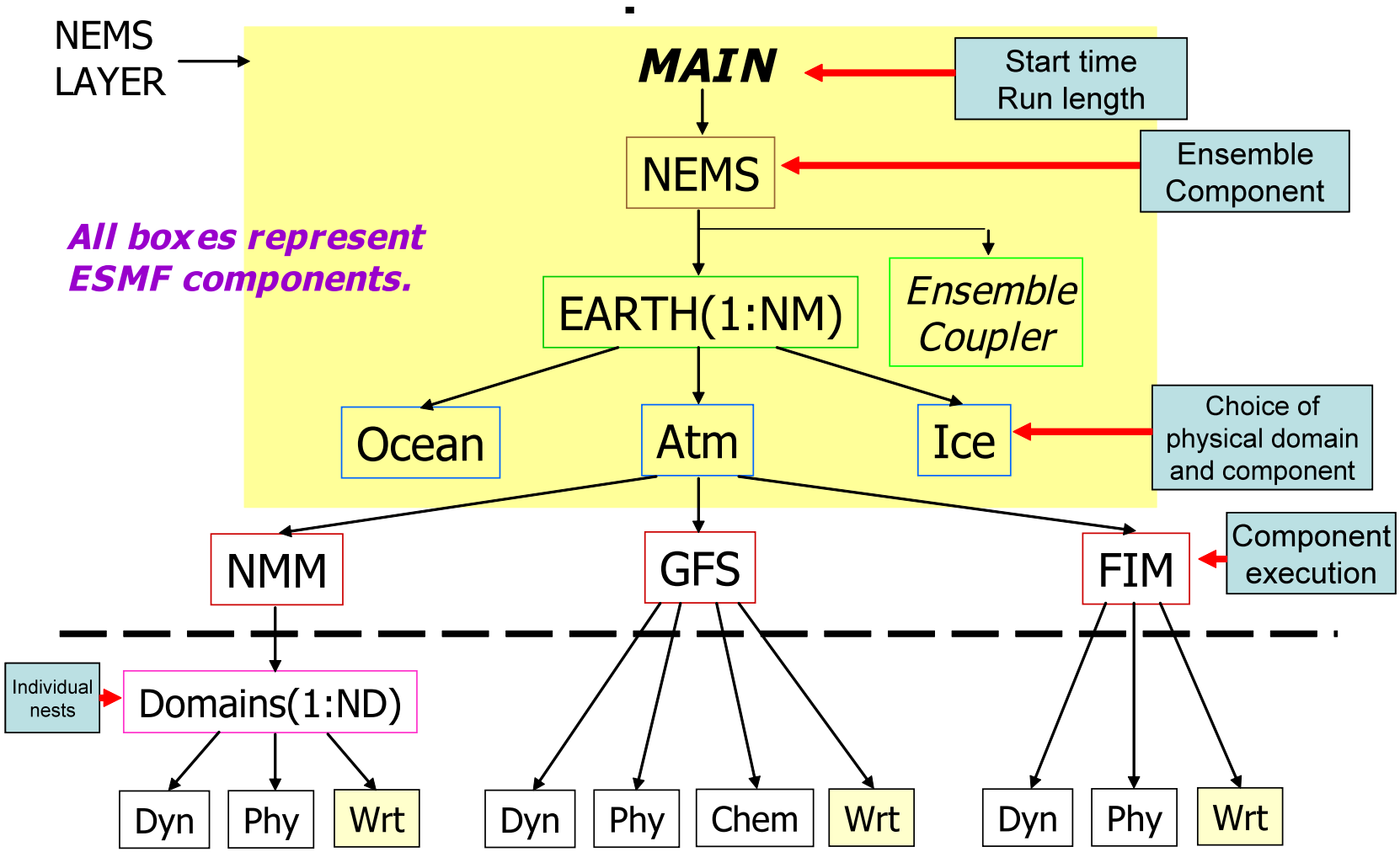
Comparison of MOM4P1 to MOM4P0d used in CFS v2



Motivation for the Development of NEMS

- **Develop a common superstructure for NCEP Production Suite components**
- **Reduce overhead costs and provide a flexible infrastructure in the operational environment**
  - **Concurrent nests**
  - **NAM executed concurrent with GFS**
  - **Stochastic ensemble generation**
  - **Coupled atmosphere/ocean/land/ice systems becoming a NOAA requirement**
- **Modularize large pieces of the systems with ESMF components and interfaces—concurrent execution**
- **NOAA contribution to the National Unified Operational Prediction Capability (NUOPC) with Navy and Air Force**

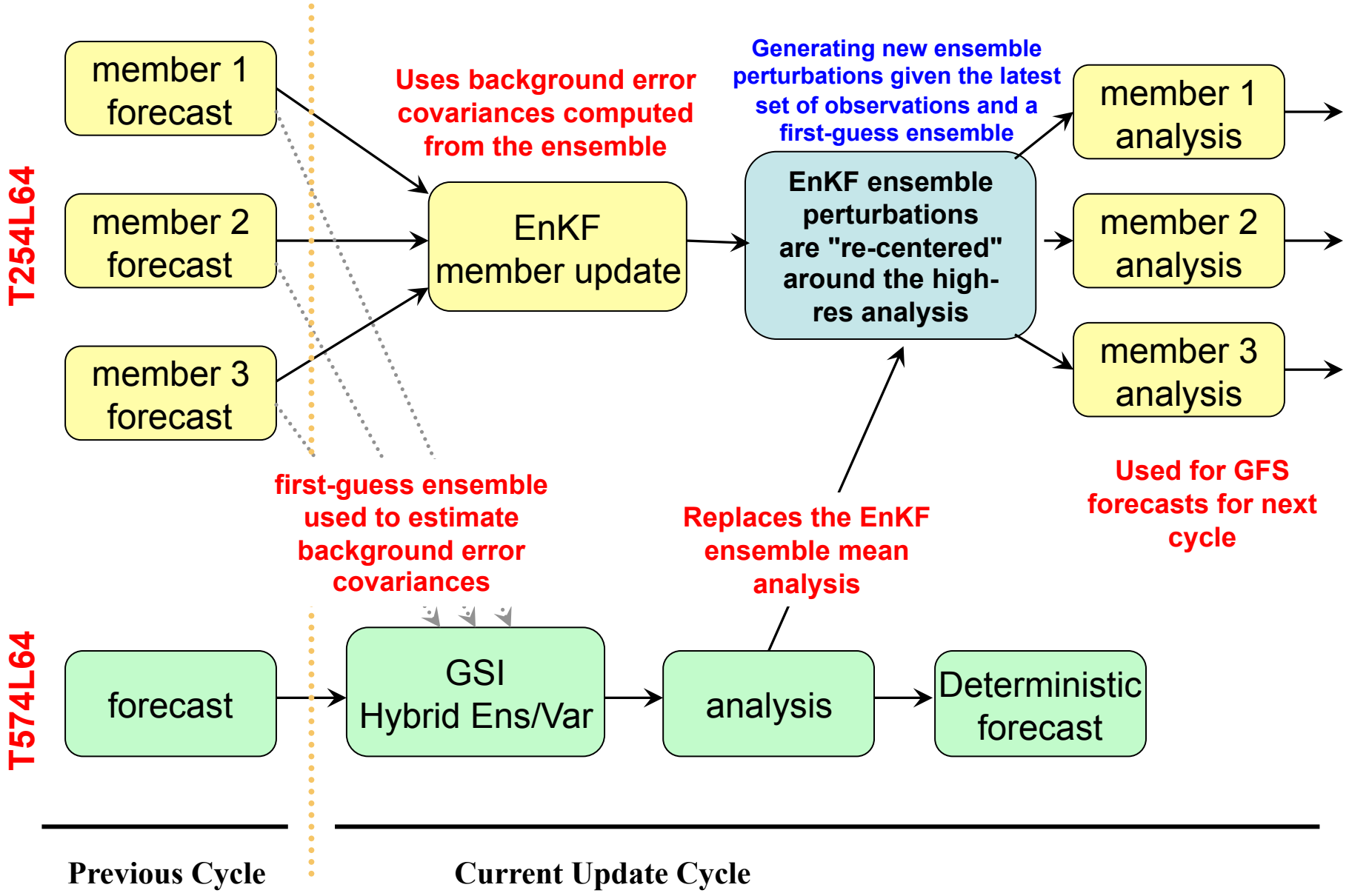
NEMS Component Structure



Below the dashed line the source codes are organized by the model developers.

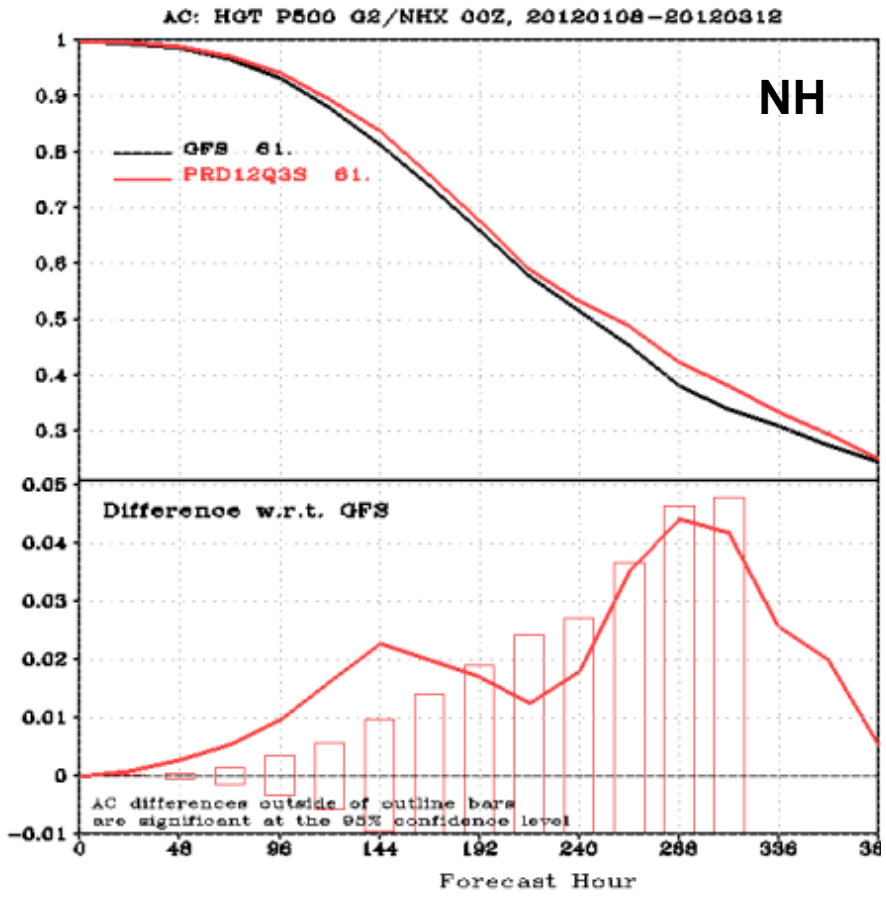
Dual-Resolution Coupled Hybrid 3DVAR/EnKF

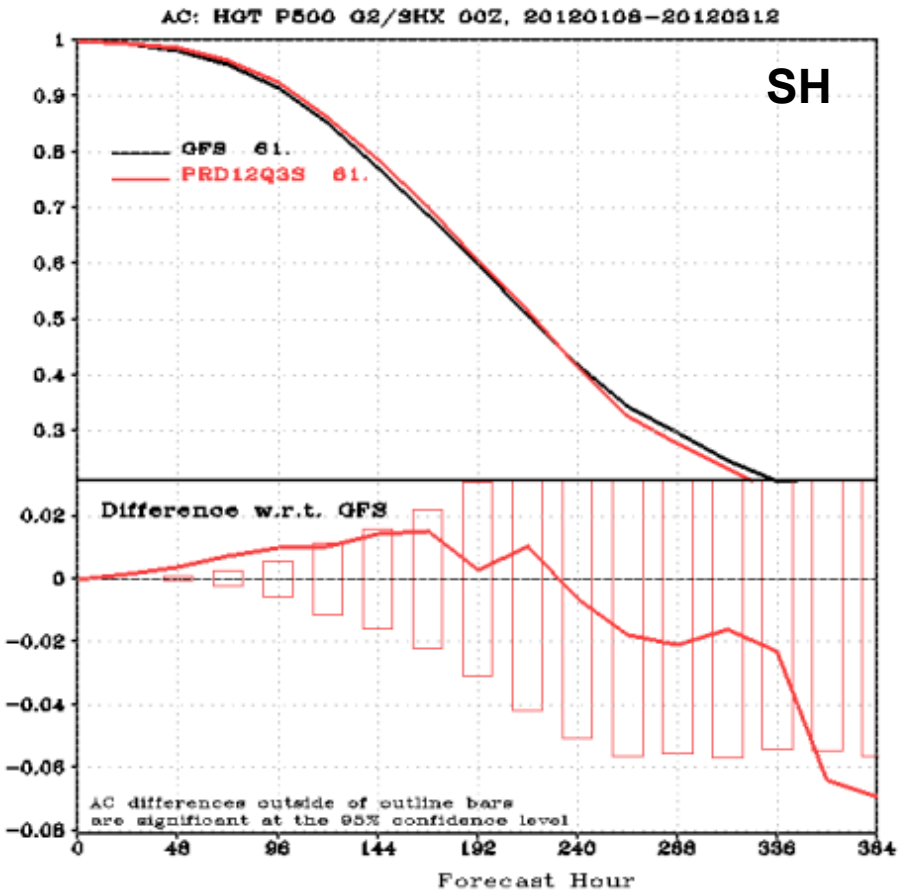
(Collaboration with ESRL, NASA/GMAO, U. Oklahoma and U. Maryland)



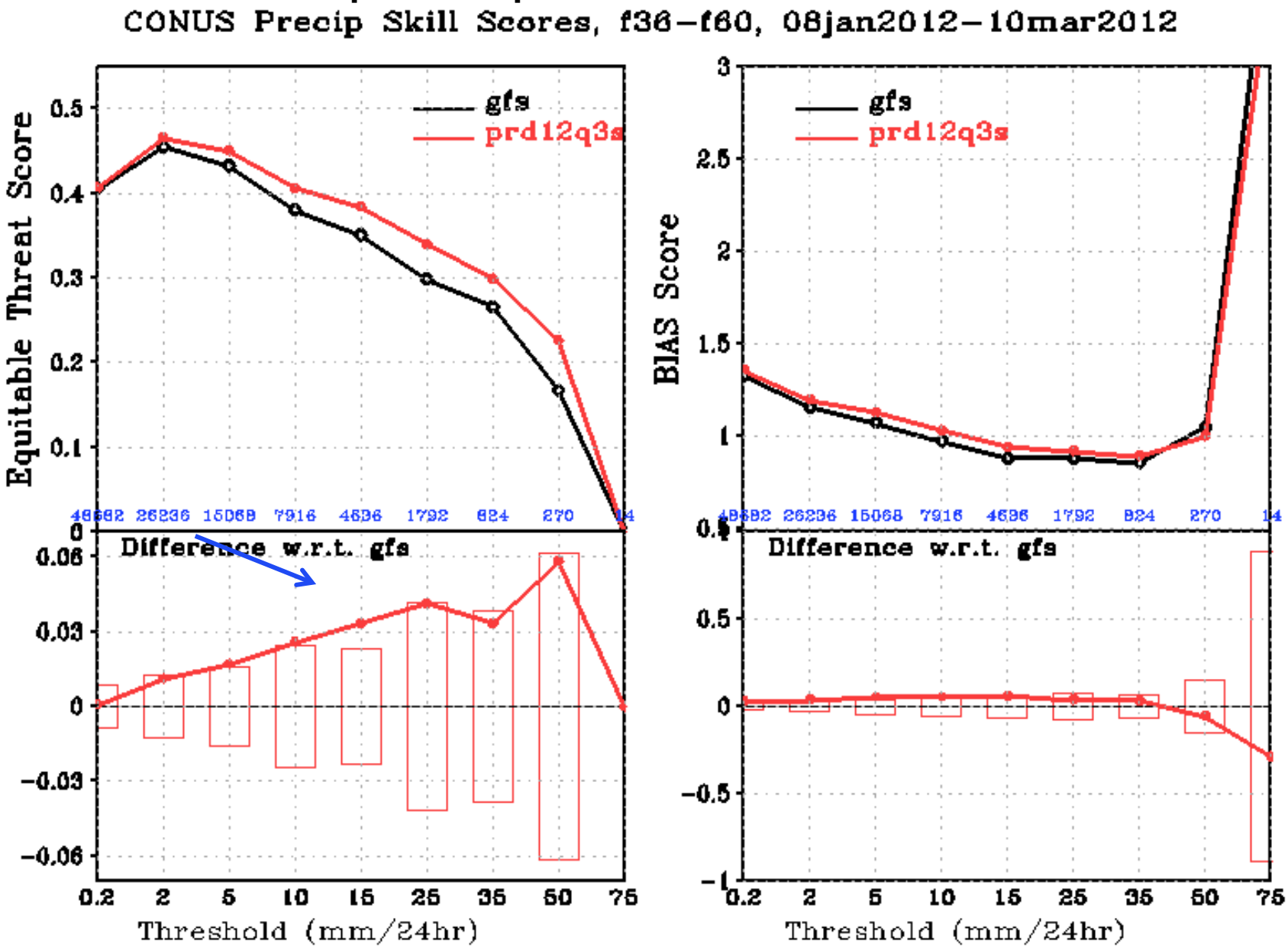
Real-Time Die-off curves from parallel test

500 hPa Anomaly correlation
January 02 – March 12, 2012





CONUS Precip Skill Scores for forecast hours 36 to 60
Experiment period : 08 Jan to 10 Mar 2012



Aerosol and Chemistry Modeling

Coupling GOCART Model to GFS

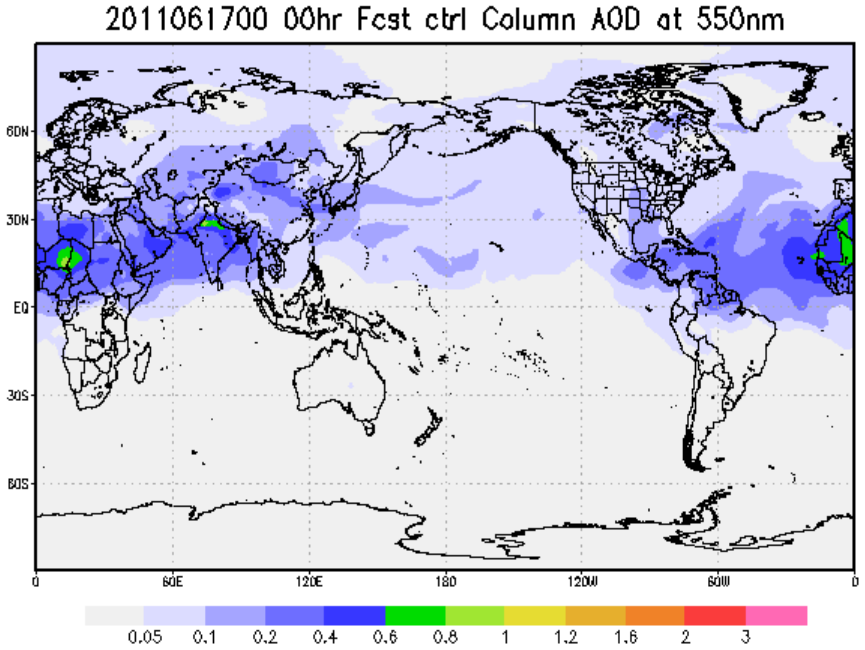
Collaboration with NASA/GMAO

NEMS GFS/GOCART Aerosol

Scheduled Implementation Q4FY12

Experimental (non-operational)

- **Executable compiled from NEMS trunk code repository**
- **120-hr dust-only forecast**
- **Once per day (00Z)**
- **3-hourly products: 3d distribution of dust aerosols (5 bins from 0.1 – 10 μm)**
- **Automatic output archive, post processing and web update since June 11, 2011**
- **Same physics and dynamics as operational GFS with the following exceptions:**
  - **Lower resolution (T126 L64)**
  - **Use RAS with convective transport and tracer scavenging**
  - **Aerosol-radiation feedback is turned off**



Column AOD @ 550nm

http://www.emc.ncep.noaa.gov/gmb/sarah/NGAC/html/realtime.fcst.html

My Thoughts on CFSV3

- The CFS V3 is to developed as a community model with input from the external research community
- The plan for this model is still under development
- Should take advantage of NEMS infrastructure with HYCOM & MOM4p1 as possible Ocean Models with Ocean Wave model and/or NST model between AM and OM
- Need also improved sea-ice and land models

Thanks

Backup Slides

AM configuration For CDAS (V2)

- **Eulerian T574L64 for fcst (0-9hr)**
- **Gravity-Wave Drag Parameterization**
  - Modified orographic GWD - automatically scales mountain blocking and gravity wave stress with resolution
- **Removal of negative water vapor**
  - Positive-definite tracer transport (TVD) scheme in the vertical replacing the central-differencing scheme to reduce negative tracers
  - Operational GSI in 2011 with reduced negative water vapor
  - Limit the borrowing of water vapor in filling negative cloud water to the maximum amount of available water vapor
- **Radiation and cloud**
  - Hourly RRTM Short Wave and Long Wave Radiation
  - Stratospheric aerosol for SW and LW and tropospheric aerosol for LW
  - SW aerosol single scattering albedo changed from 0.90 to 0.99
  - SW aerosol asymmetry factor changed. New aerosol climatology used.
  - Maximum/random cloud overlap ; Time and spatially varying CO2
  - Minimum specific humidity changed from 1.0e-5 to 1.0e-7 kg/kg
  - Yang et al. (2008) scheme to treat the dependence of direct-beam surface albedo on solar zenith angle over snow-free land surface

OM - MOM4p0d

- **Version**
  - GFDL's Modular Ocean Model Version 4.0d (MOM4p0d)
  - The code has been rewritten from earlier versions and is now in Fortran 90
  - Supports 2-D domain decomposition for improved efficiency in parallel environments
  - Uses Murray (1996) tripolar-grid to avoid pole problem (Arctic).
- **Domain and Resolution**
  - Global domain (previous version did not have an interactive Arctic Ocean).\
  - Arakawa B grid with resolution 1/2°x1/2° (1/4° within 10° of the equator)
  - 40 Z-levels with variable resolution (23 levels in the top 230 meters).
- **Physics**
  - Fully interactive ice model
  - Equation of state is based on McDougall et al. (2002) formulation
  - Non-local boundary layer parameterization, KPP, of Large et al. (1994)
  - Isoneutral lateral diffusion (Griffies et al., 1998)
  - Boussinesq formulation and has a free surface.

AM Physics

Planetary Boundary Layer and vertical diffusion (PBL)

- **Nonlocal PBL scheme originally proposed by Troen and Mahrt (1986) and implemented by Hong and Pan (1996)**
- **First order vertical diffusion scheme**
- **PBL height estimated iteratively from ground up using bulk Richardson number**
- **Diffusivity calculated as a cubic function of height and determined by matching with surface fluxes**
- **Counter-gradient flux parameterization based on the surface fluxes and convective velocity scale.**
- **Recent update – stratocumulus top driven vertical diffusion scheme to enhance diffusion in cloudy regions when CTEI exists**
- **For the nighttime stable PBL, local diffusivity scheme**
- **Background vertical diffusion:**
  - **Exponentially decreasing with height for heat and moisture**
  - **A constant value of 3 m2/s for momentum up to sigma=0.2 and exponentially decreasing above**
  - **Decreased by 70% in inversion layer below 2.5km over ocean**

Atmospheric Model Physics

Deep convection parameterization

- Simplified Arakawa Schubert (SAS) scheme is used operationally in GFS (Pan and Wu, 1994, based on Arakawa-Schubert (1974) as simplified by Grell (1993))
- Includes saturated downdraft and evaporation of precipitation
- A single deepest possible cloud-type per every time step
- Cloud water is detrained from every cloud layer
- Specified finite entrainment and detrainment rates for heat, moisture, and momentum
- In the sub-cloud layers, the entrainment rate is inversely proportional to height and the detrainment rate is set to be a constant equal to the cloud base entrainment rate
- Above cloud base, an organized entrainment is added, which is a function of environmental relative humidity
- This implementation reduced occurrences of excessive grid-scale precipitation

AM Physics

Unified Radiation Package for NCEP models

Features::

Standardized component modules, General plug-compatible, Simple to use, Easy to upgrade, Efficient, and Flexible for future expansion.

References:

- Hou et al. (2012): NCEP Office Note (in preparation)
- Hou et al. (2002): NCEP Office Note 441 (ref for clouds, aerosols, and surface albedo processes)
- Mlawer and Clough (1998): Shortwave and longwave enhancements in the rapid radiative transfer model, in Proceedings of the 7th Atmospheric Radiation Measurement (ARM) Science Team Meeting.
- Mlawer and Clough (1997): On the extension of rapid radiative transfer model to the shortwave region, in Proceedings of the 6th Atmospheric Radiation Measurement (ARM) Science Team Meeting.
- Mlawer et al. (1997): RRTM, a validated correlated-k model for the longwave, JGR.

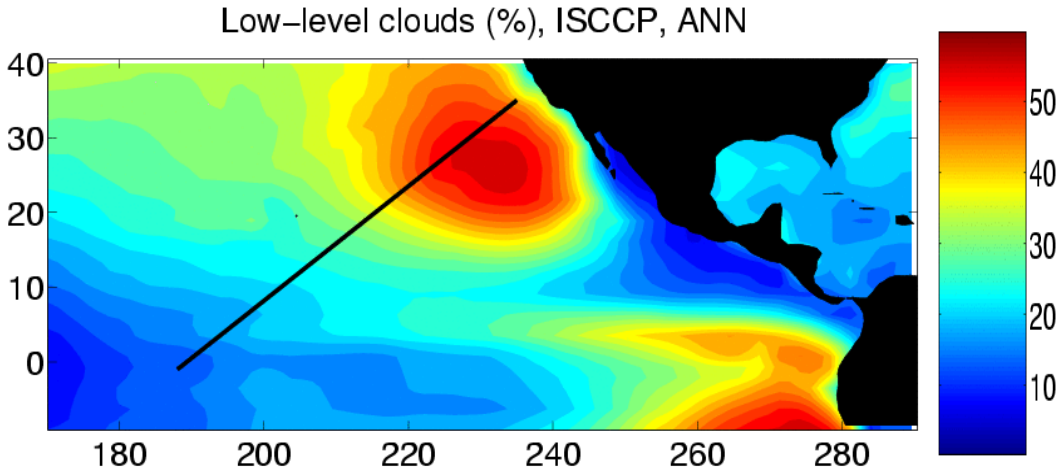
External Collaborations

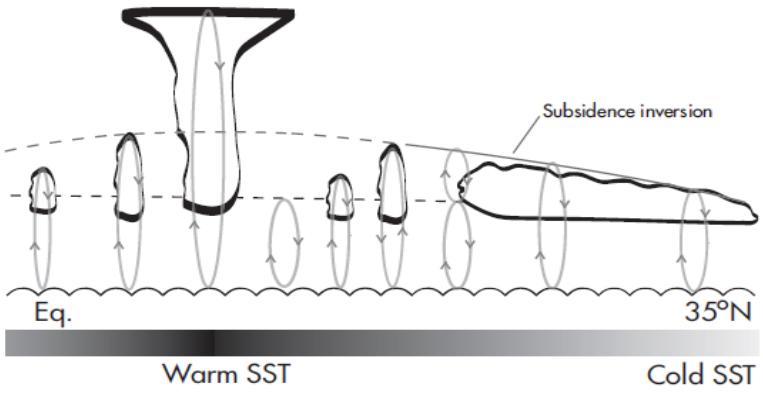
Climate Processes Team sponsored climate physics development

Please refer to Hualu Pan's presentation on this topic and associated internal research within EMC

Stratocumulus to Cumulus Transition CPT

Goal: Improve the representation of the cloudy boundary layer in NCEP GFS and NCAR CAM5 with a focus on the subtropical stratocumulus to cumulus (Sc-Cu) transition





NCEP H. Pan (PI), J. Han, R. Sun
NCAR S. Park (PI), C. Hannay
JPL J. Teixeira (CPT lead PI), M. Witek
U. Washington C. Bretherton (PI), J. Fletcher, P. Blossey
UCLA R. Mechoso (PI), H. Xiao
LLNL S. Klein (PI), P. Caldwell

NOAA funded
Aug. 2010 - 2013
(additional internal JPL and DOE funds)

GFS/CFS motivations for CPT

Enhance interactions with climate science community

- Operational GFS/CFS had insufficient subtropical Sc.

  In 2010 NCEP introduced new shallow Cu and PBL schemes to operational GFS (Han&Pan 2011) to address this.

- GFS/CFS needs to update its suite of climate bias metrics and use them more rigorously for model evaluation.

- Moist physical parameterization suite could be better tested and improved with controlled GCSS-style single-column tests.

- New parameterization approaches (EDMF turbulence, dual-MF shallow Cu, pdf cloud fraction) could improve GFS/CFS.

- Better GFS/CFS reanalyses benefit climate community

CPT Current Main Tasks

a) Better coupled/uncoupled climate diagnostics for GFS (UCLA, NCEP, NCAR)

b) GCSS Sc/Cu cases with NCAR and NCEP SCMs, and LES (UW, NCAR, NCEP, JPL)

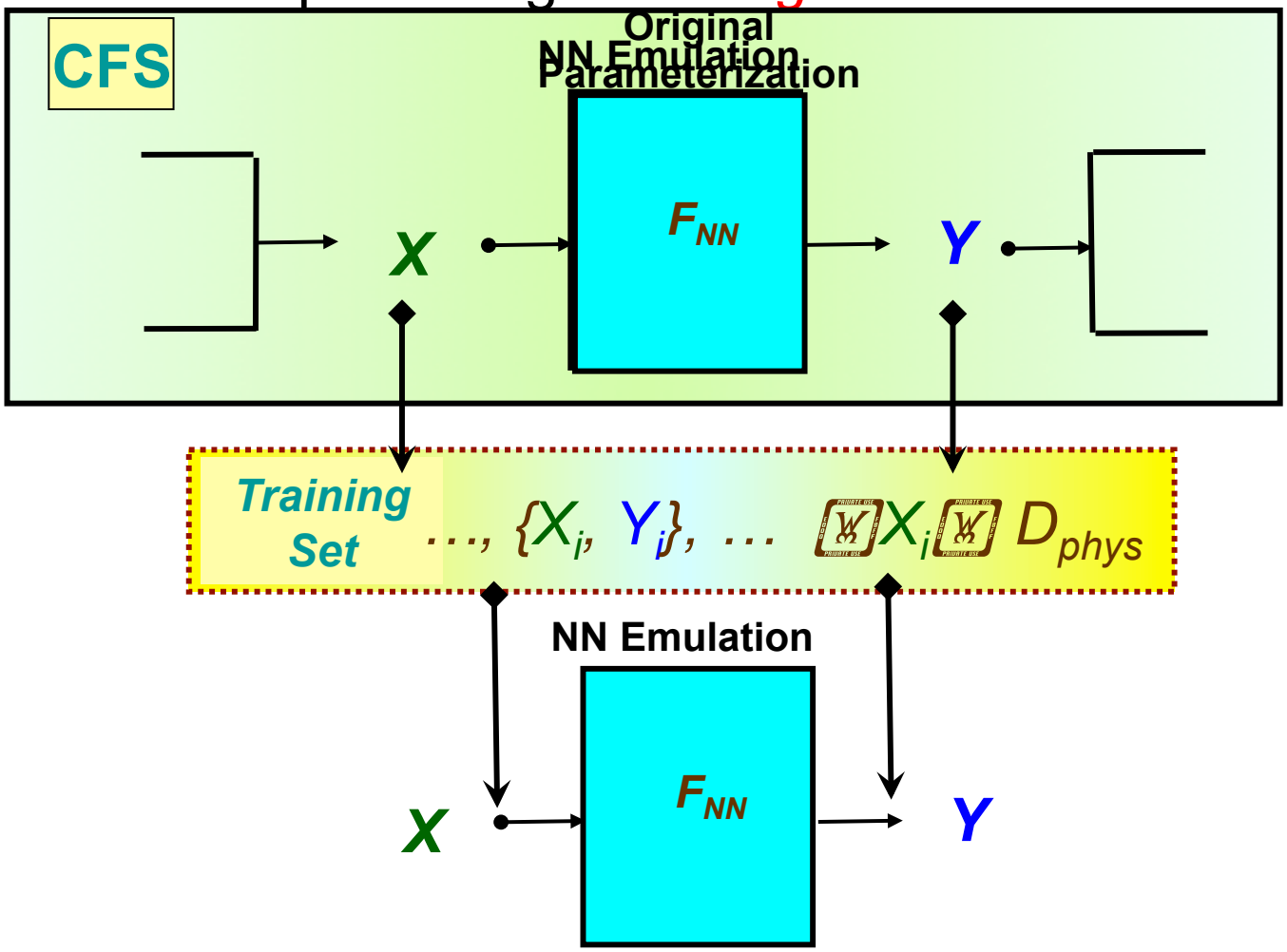
c) Development/testing of PDF cloud and new convection/turbulence schemes in NCAR (LLNL, NCAR)

d) Development/testing of EDMF approach in NCAR, NCEP (JPL, NCAR, UW, NCEP)

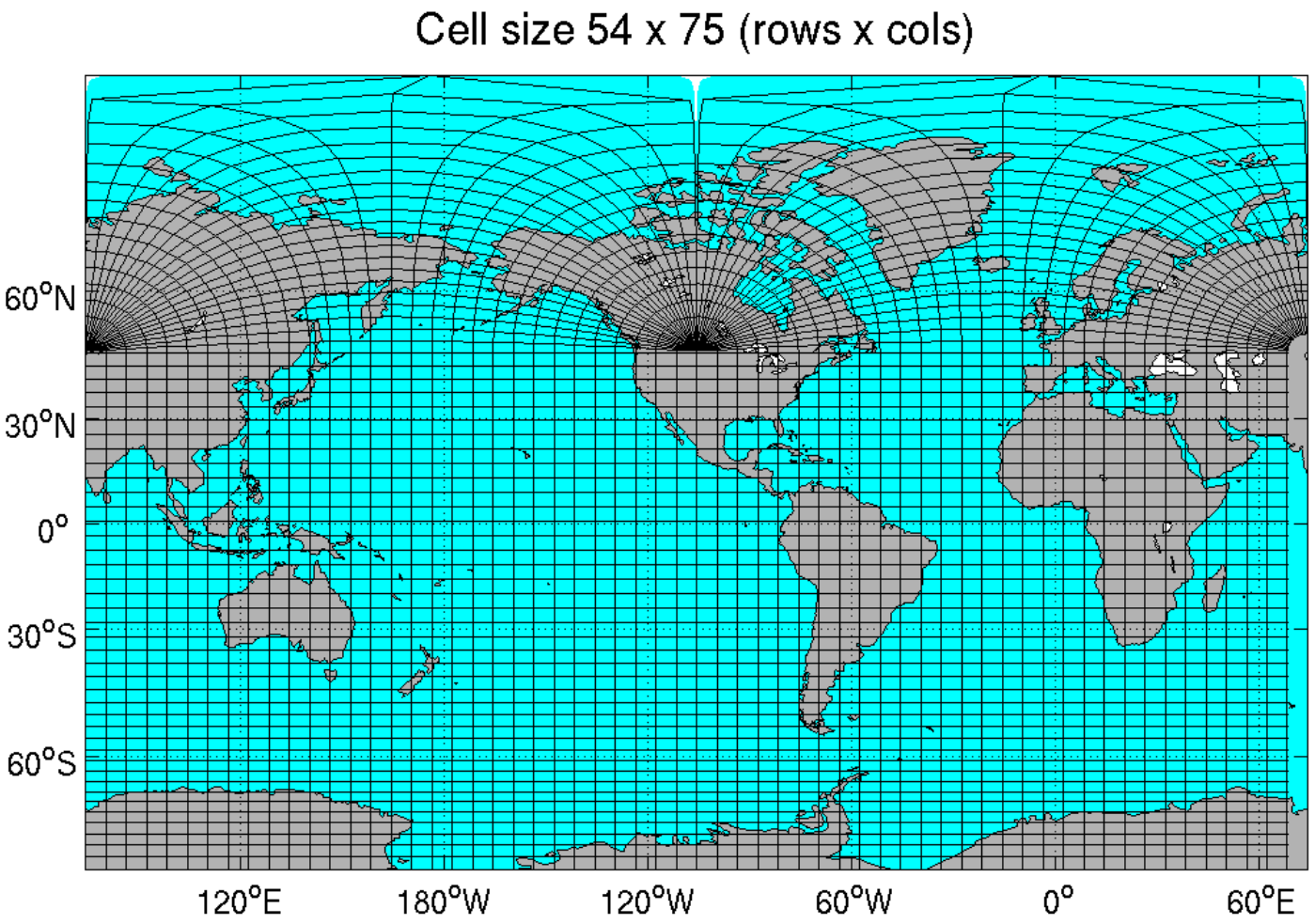
$$\overline{w'\varphi'} = -k\frac{\partial \bar{\varphi}}{\partial z} + M(\varphi_u - \bar{\varphi})$$ Siebesma & Teixeira, 2000

NN Emulations of Model Physics Parameterizations

are developed using *Learning from simulated Data*



1/12 Degree PAN-AM Grid



NEMS
System Characteristics

- **Divide atmospheric models down into Dynamics and Physics components but no further**
- **Take history file I/O outside the science parts and into a common Write component**
- **Keep science code and parallelization code in the respective models the same as before**
- **Follows NUOPC defined standards and protocols**
- **Eventual support to community through Developmental Test Center (DTC)**

http://www.emc.ncep.noaa.gov/NEMS/